Using Full Rainfall Rate Distribution for Rain Attenuation Predictions over Terrestrial Microwave Links in Malaysia

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Abstract

The use of full rainfall rate distribution for the prediction of rain attenuation over terrestrial microwave links in Malaysia is presented in this letter. The experimental data consist of four-year measured rainfall rates and one-year rain attenuation measurements over six geographically spread DIGI MINI-LINKs operating at 15 GHz. The test results show that ITU-R model does not perform well for rain attenuation predictions in tropical Malaysian climate.

Keywords

Tropical Climates; Rainfall Rate CD; Terrestrial Microwave Links

Introduction

The heavy traffic and insufficient bandwidths are the major difficulties encountered by microwave engineers working on radio systems operating at frequencies above 10 GHz in tropical regions due to prevalence of convective rain drops (Ajayi G. O., 1990). These problems have motivated the research community to balance the trade-off between band width availabilities and rain attenuation issues at higher frequencies. Therefore attenuation due to rainfall plays a significant role in the design of terrestrial and Earth-satellite radio links especially at frequencies above 10 GHz (Crane, R.K , 2003).

The ITU-R recommendations (ITU-R P.530-14, 2012 and P.838-3, 2005) have provided a methodological approach for predicting the rain attenuation on any terrestrial radio link. However, empirical evidences have indicated that the ITU-R models poorly predict the cumulative distribution (CD) of rain attenuation when applied to microwave links located in tropical regions, thereby leading to underestimation and a poor prediction (Moupfouma F, 2009, Da Silva Mello et. Al., 2007).

Silva Mello et al. have reported that the extrapolation procedure adopted by the current ITU-R P.530-14 was the major limitation of the prediction method. The ITU-R method predicts the same rain attenuation CD for two regions with different rainfall rate regimes, provided they have same value of $A_{0.01}(dB)$.The poor prediction of the current ITU-R approach can be addressed by using full rainfall rate distribution as an input for predicting rain attenuation. Silva Mello et al. have therefore provided a modified method by introducing the concept of effective rainfall rate, as follows:

$$d_{eff} = \frac{1}{d_0 + d}\int_{d_0}^{d} d(x)dx = \frac{1}{1+d_0}d \qquad (1)$$

The power-law technique proposed by Da Silva Mello provides fairly more accurate results for the tropical climates than the exponential law used by the current ITU-R method. This fact was also established in our previous work (Abdulrahman, A. Y., et al., 2012), where various rain attenuation prediction methods were tested against the measured data over six DIGI MINI-LINKs operating at 15 GHz in Malaysia.

Analysis of Experimental Data

One-year rain attenuation data, sampled every second, were collected from six operational point-to-point microwave links of DiGi Telecommunications Sdn. Bhd., Malaysia. Each of the microwave systems consists of a microwave MINILINK operating at 15 GHz with data acquisition and processing system. Both antennas are horizontally polarized and the elevation angle is approximately zero degrees. Wet

antenna losses have been extracted from the rain attenuation measurement by covering the antennas with radome in order to achieve reliable results. More so, scintillations and other atmospheric absorptions along the propagation path have not been considered in the study.

The MINI-LINKs have availability of 99.95 % and their specifications are given in Table I. The dynamic range of the maximum signal strength is about 50 dB for excess (i.e. rain) attenuation. This is adequately suitable for covering the entire dynamic range of rain attenuation for this study, since the highest total path attenuation measured is 49.32 dB at 0.001 % of the time. Four year rainfall rates data were also collected at each location of the MINI-LINKs, using a Casella rain gauge. The reader is referred to our previous work (Abdulrahman, A. Y., et al., 2012), for comprehensive information on rain rate and attenuation measurements. Figures 1 and 2 show the rainfall rate and rain attenuation probability distributions over the six sites, respectively, while Figure 3 shows the equal probability plots of concurrently measured rainfall rate and rain attenuation exceeding $\% p$ of the time for the six sites.

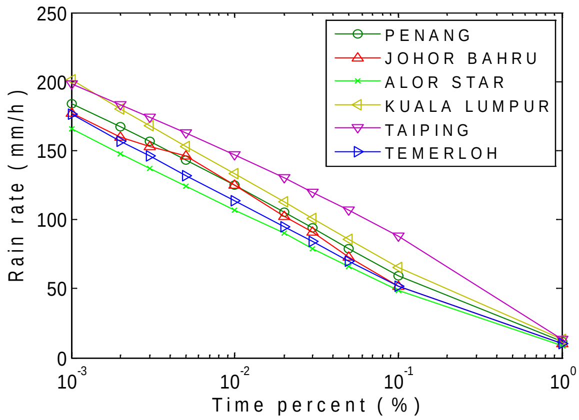

FIG 1. PROBABILITY DISTRIBUTION OF RAINFALL RATE.

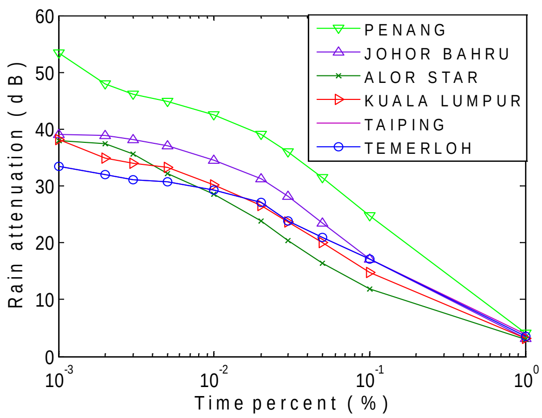

FIG 2. PROBABILITY DISTRIBUTION OF RAIN ATTENUATION

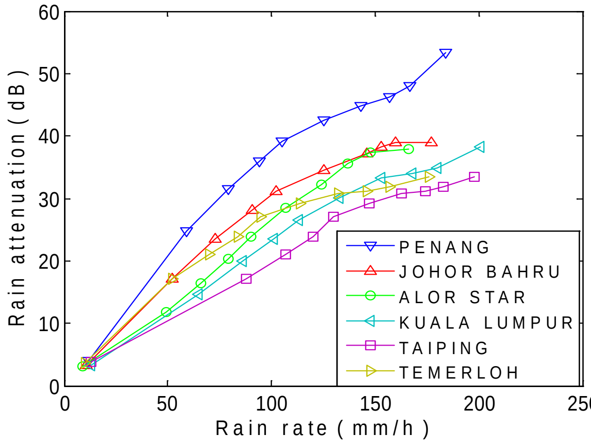

FIG 3. EQUAL PROBABILITY PLOTS OF RAIN RATE AND RAIN ATTENUATION EXCEEDANCE

TABLE I. SPECIFICATIONS OF THE 15GHz LINK

Type of antenna	**Front-fed parabolic**	
Frequency band (GHz)	14.80---15.30	
Polarization	Horizontal	
Maximum transmit power(dBm)	+18.0	
BER Received threshold (dBm)	-84.0	
Antenna beam width	2.3^0	
Dynamic range (dB)	50.00	
Antenna for both transmit and receive side	Size (m)	Gain (dBi)
	0.6	37.0

Results and Discussions

By statistically analyzing the experimental data presented in Figures 1, 2 and 3, it is possible to investigate the relationship between theoretical specific rain attenuation $\gamma_{\% p}(R_{\% p})$ and effective specific rain attenuation $\gamma_{eff}(R_{eff})$, as shown in Figure 4. The plots of measured and effective rain rates at different exceeding probabilities are shown in Figure 5.

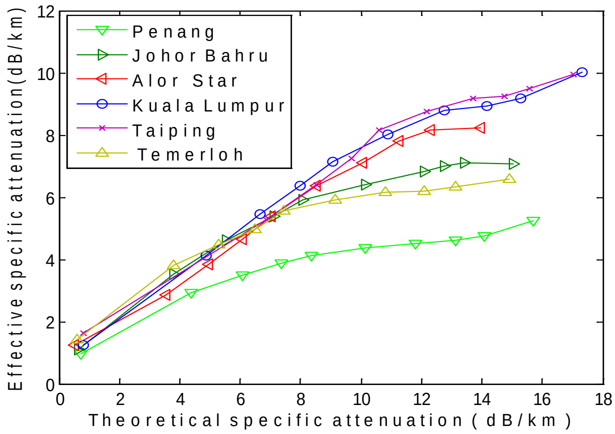

FIG 4. COMPARISON OF THE EFFECTIVE AND THEORETICAL SPECIFIC ATTENUATIONS.

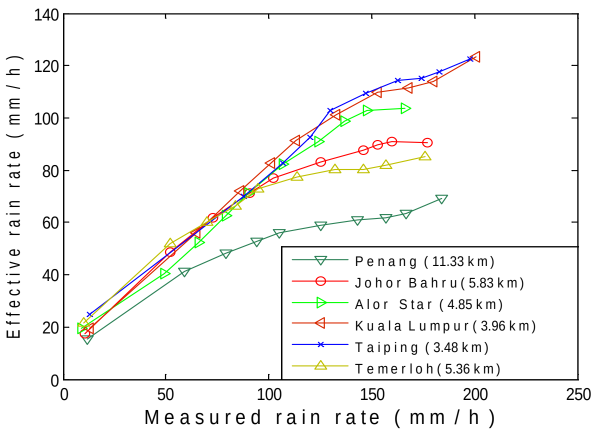

FIG 5. EFFECTIVE RAINFALL RATE AGAINST ACTUAL RAINFALL RATE.

The empirical relationship between these two quantities γ_{eff} and $\gamma_{\%p}$ is given by the following ratio:

$$\frac{\gamma_{eff}}{\gamma_{\%p}} = \frac{kR_{eff}^{\alpha}}{kR_{\%p}^{\alpha}} \tag{2}$$

Solving Equation (2) to derive

$$R_{eff} = \left(\frac{1}{k}\gamma_{eff}\right)^{1/\alpha} = R_{\%p}\left(\frac{\gamma_{eff}}{\gamma_{\%p}}\right)^{1/\alpha} \tag{3}$$

The effective rain rate was derived as a function of measured rain rate, as follows:

$$R_{eff} = 3.7158\, R_{\%p}^{0.7208 - 0.1224/d} \tag{4}$$

Therefore, the attenuation exceeded at $\%p$ of time is modified as follows:

$$A_{\%p} = \gamma_{eff}\, d_{eff} = k\left[R_{eff}(R_{\%p}, d)\right]^{\alpha} \frac{d}{1 + d/d_0(R_{\%p})} \tag{5}$$

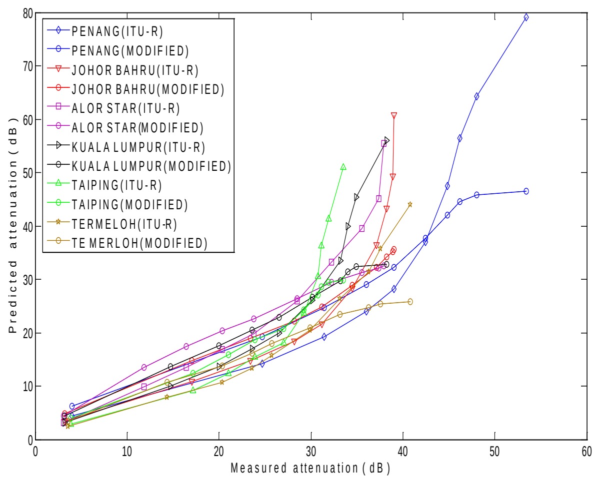

FIG 6. SCATTER PLOT OF MEASURED AND PREDICTED RAIN ATTENUATION OVER SIX DIGI MINI-LINKS.

Figure 6 shows the comparison between the measured and predicted attenuation over the MINI-LINKs. It is concluded from Figure 6 that the ITU-R method does not seem to be accurate for predicting rain attenuation over terrestrial links in Malaysia. On the other hand, the proposed method seems to match the measured values more accurately, with up to 81 % reduction in relative RMS errors compared to ITU-R method.

The relative error variable used to assess the proposed model performance is given by:

$$E = \frac{A_{\%p,\,predicted} - A_{\%,p\,measured}}{A_{\%,p\,measured}} \times 100\,\%;\ 0.001 < \%p < 1\%$$

Table II shows the mean μ_{ei}, standard deviation σ_{ei} and root mean square D_{ei} of the test variable for each method, as recommended by ITU-R P. 311-13.

TABLE II. PERCENTAGE ERRORS AND RMS COMPARISON

	variable	0.1	0.01	0.005	0.003	0.001
ITU	μ_{ei}	-0.0284	-0.0287	-0.0253	-0.0234	-0.0223
	σ_{ei}	0.2489	0.2489	0.2485	0.2483	0.2483
	D_{ei}	0.2505	0.2506	0.2498	0.2494	0.2493
Modified Method	μ_{ei}	-0.0007	0.0068	0.0137	0.0151	0.0282
	σ_{ei}	0.0494	0.0493	0.0488	0.0787	0.7868
	D_{ei}	0.0494	0.0488	0.0468	0.0767	0.0735

Conclusions

The use of full rainfall rate distribution for the prediction of rain attenuation over terrestrial microwave links in Malaysia is presented in this letter. The test results have shown that the ITU-R model does not perform well for rain attenuation predictions in tropical Malaysian climate. The proposed method may also be tested against measurement data in similar tropical climates.

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